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DESCRIPTION

METHOD FOR MANUFACTURING BONDED MAGNET

Technical Field

[0001] The present invention relates to a method for manufacturing a bonded magnet and, more particularly, to a method suited to the manufacturing of a thin bonded magnet, etc. exhibiting excellent magnetic properties.

Background Art

[0002] Various kinds of actuators, motors, etc. have been demanded to have higher performance and smaller dimensions, and accordingly, small-sized and powerful permanent magnets have been required. Examples of such permanent magnets include sintered magnets, etc. But, recently, bonded magnets exhibiting excellent moldability, physical properties, treating properties, etc. have been frequently used. The bonded magnets are manufactured by solidifying an isotropic magnet powder and an anisotropic magnet powder with resin, etc., but where high magnetic properties are required, the anisotropic magnet powder has been frequently used.

[0003] In the case of the bonded magnets composed of the anisotropic magnet powder, in order to enhance the magnetic properties thereof, it is important to orient the anisotropic magnet powder sufficiently in a magnetic field, thereby preparing a compact molded body. The methods for manufacturing these bonded magnets are disclosed in the following patent document 1 and patent document 2, ex.

[0004] Patent document 1 discloses a single-stepped molding method of supplying, orienting and compression-molding a compound composed of an anisotropic magnet powder and a thermosetting resin in a single molding die which is heated to 150 ℃.

[0005] Patent document 2 discloses a two-stepped molding method which divides the method of patent document 1 into two steps, and includes a pre-molding process of supplying, orienting and lightly compression-molding a material powder in a first molding die which is heated to 150 ℃ to manufacture a pre-molded body, and a main molding process of compression-molding the pre-molded body strongly in a second molding die which is heated to 150 ℃ to make the pre-molded body compact.

[0006] Patent document 1: Publication of unexamined JP patent application No. Hei8-31677

Patent document 2: Publication of unexamined JP patent application No. Hei10-22153

Patent document 3: Publication of unexamined JP patent application No. Hei9-312230

Disclosure of Invention

[0007] In the above-described methods, the compound is directly supplied (weighed and filled) into a cavity of the molding die which is heated to 150 ℃. As is apparent from the above-described patent documents, the temperature of 150 ℃ is the melting temperature of the thermosetting resin in the compound. When the compound is supplied to the molding die which is

heated to such a high temperature, the thermosetting resin in the compound locally softens or melts, and a large amount of the compound adhere to a wall surface of the cavity of the molding die. When the compound attaches to the wall surface, passages for filling the compound become narrow, and consequently, a predetermined amount of compound is difficult to sufficiently fill in the cavity. And the weighed amount of the compound in each product scatters, and the compound is not homogeneously filled in each product. This results in the magnetic properties of the bonded magnet lowering and becoming inhomogeneous. In particular, these phenomena readily appear where the thin bonded magnets are manufactured using the molding die of which a cavity opening is narrow.

[0008] In addition, the above-described patent document 3 discloses a two-stepped method of primarily molding a mixture of an anisotropic magnet powder and a resin at a temperature not higher than the initial softening temperature, and secondarily molding an obtained primary compact in a heated magnetic field of which the temperature is not lower than the initial softening temperature and not higher than the initial hardening temperature, thereby obtaining a secondary compact. And the obtained secondary compact is subjected to only the heating treatment (curing treatment) for hardening it finally.

[0009] With the method of this patent document 3, the orientation of the magnetic field and the compression molding are carried out in the secondarily molding process simultaneously so that the molding pressure is too high to orient the magnetic field, but is too low to carry out the pressure molding.

This results in the anisotropic magnet powder being not oriented sufficiently, and the density of the resultant secondary compact lowering, and consequently, the magnetic properties of the bonded magnet which was hardened become insufficient, because the magnetic properties of the anisotropic magnet powder are not exhibited sufficiently.

[0010] The present invention has been made considering these circumstances, and has an object of providing a method for manufacturing a bonded magnet exhibiting uniform and stable magnetic properties.

[0011] The present inventors have earnestly studied to solve these problems, and after repeated tries and errors, they have newly found that by supplying the compound into the cavity of which the wall temperature is close to room temperature, the compound uniformly fills the cavity without attaching to the wall surface thereof, and have completed the present invention by developing the above-described findings.

[0012] The method for manufacturing a bonded magnet in accordance with the present invention is characterized in that the method includes a weighing and filling process of weighing and filling a compound composed of an anisotropic magnet powder and a thermosetting resin in a cavity of which the wall temperature is lower than the softening point of the thermosetting resin, an orienting process of applying an orientation magnetic field to orient the anisotropic magnet powder while heating the weighed and filled compound or a power compact thereof to the above-described softening point or more so that the thermosetting resin becomes softened or molten, and compactly

bonding process of heating and compression-molding the anisotropic magnet powder and the thermosetting resin after the orienting process to form a bonded magnet compact in which the oriented anisotropic magnet powder is compactly bonded with the thermosetting resin.

[0013] In accordance with the present invention, in the weighing and filling process, the compound is weighed and filled in the cavity of which the wall temperature is lower than the softening point of the thermosetting resin in the compound. This results in the thermosetting resin in the compound being not softened in the weighing and filling process to restrain the compound from attaching to the wall surface of the cavity. As a result, the compound is smoothly filled into the cavity, the filling amount becomes stable, and the distribution of the compound in the cavity becomes approximately homogeneous. Therefore, the bonded magnet of high quality, of which the density and the magnetic properties do not scatter, and the dimensional accuracy is excellent, can be mass-produced stably at a good yield rate.

[0014] The term "softening point" of the thermosetting resin basically means the softening point of a virgin material of the thermosetting resin, which has not been subjected to any heat history. After heated, this term means the softening point thereafter. This softening point depends on the kind (molecular structure, composition, etc.) of the thermosetting resin. In many cases, the compound contains a hardening agent, hardening promoting agent, surface active agent, etc. in addition to the anisotropic magnet powder and the thermosetting resin, but the above-described softening point is the softening point of a simple substance (monomer) of the thermosetting resin to

be used in the present method.

[0015] Examples of the wall temperature of the cavity include room temperature. The softening point of the thermosetting resin to be used in the bonded magnet depends on the kind of the thermosetting resin, but is normally in the vicinity of 90 ℃. Therefore, it is sufficient to raise the wall temperature of the cavity to the temperature range from about 30 to 60 ℃,

[0016] The "initial attaching temperature" can be used in place of this softening point. The initial attaching temperature is the temperature at which the compound begins to attach to the wall surface of the cavity. The above-described softening point can be considered to indicate this initial attaching temperature. But, strictly speaking, the initial attaching temperature is not always determined by the kinds of the thermosetting resin, and cannot be defined identical to the softening point. In order to specify this initial attaching temperature, troublesome experiments, etc. may be required actually. Accordingly, in accordance with the present invention, in order to eliminate such troubles, the wall temperature has been determined based on the above-described "softening point".

[0017] The measuring position of the wall temperature of the cavity is not limited specifically, because the entire wall of the cavity is normally at an approximately identical temperature. But, only the temperature in the vicinity of an inlet opening (upper opening, ex.) of the cavity greatly influences the filling of the compound in the cavity. Accordingly, the wall temperature may be determined based on the temperature in the vicinity of the inlet opening.

[0018] The method for manufacturing the bonded magnet in accordance with the present invention includes a weighing and filling process, orienting process and compactly bonding process. These processes may be carried out in a single molding device or may be arbitrarily carried out in two or three molding devices. But, it is preferable that these three processes are carried out separately in different molding devices considering the convenience of the temperature control of the molding die, freedom of the selection of the materials of the molding die, operation rate of the orientation magnetic field device and pressing device, or the like. With this arrangement, the temperature of the molding die does not need to be varied in every process, and the lifetime of the molding die can be extended. In addition, since the above-described three processes are carried out in different molding devices, the operation rate of each molding device is improved, and the bonded magnet can be mass-produced in a short tact time. In particular, by adjusting the manufacturing tact time per one process and the number of the molding devices required in each process, each molding device can be made into a full-operating state so that the mass-productivity can be further improved. And in accordance with the present invention, upon mass production, bonded magnets of stable quality, each being excellent in magnetic properties and dimensional accuracy, can be obtained efficiently at a good yield rate (with a low percent defective).

Brief Description of the Drawing

[0019] FIG. 1 is a schematic sectional view of a first molding device used in a weighing and filling process in accordance with the present invention.

FIG. 2 is an enlarged sectional view of the vicinity of a cavity of the first

molding device.

FIG. 3 is a schematic sectional view of a second molding device used in an orienting process in accordance with the present invention.

FIG. 4 is a schematic sectional view of a third molding device used in a compactly bonding process in accordance with the present invention.

FIG. 5 is a perspective view showing a ring-shaped thin bonded magnet subjected to a radial orientation.

Best Mode for Carrying out the Invention

[0020] A. Embodiment

Hereinafter, the present invention will be explained in more detail with reference to embodiments.

(1) Weighing and filling process

The weighing and filling process is the process of filling a predetermined amount of compound in a cavity. The compound is weighed by leveling, for example, when the compound is filled in the cavity. As described above, in the case of the present invention, the wall temperature of this cavity is lower than the softening point of the thermosetting resin, and accordingly exhibits excellent filling properties.

The effect of the present invention is remarkably achieved where an inlet (opening) of the cavity for filling the compound is narrow and, more specifically, where the relative width ratio of the minimum width (W) of the cavity to the average particle diameter (d) of the compound ranges from about 1 to 15. When the upper limit of the relative width ratio decreases to 10, 9, 8, 7, 6, the effect of the present invention becomes remarkable. And it is preferable that the lower limit thereof is about 2, 3, 4, 5 considering the

actual thickness of the bonded magnet and the filling properties of the compound.

[0021] Of course, even where the relative width ratio exceeds the above-described range, the effect of the present invention, such as the improvement of the filling properties of the compound, is obtained. Where the relative width ratio is considerably great, filling passages for the compound are readily obtained even if the wall temperature of the cavity is higher than the softening point and the compound attach to the wall thereof. Therefore, by applying vibrations properly upon filling or after filling of the compound, the compound can be filled in the cavity approximately homogeneously. Accordingly, the present invention is especially effective where the relative width ratio is in such a small range as described above.

[0022] It is preferable to determine the minimum width of the cavity considering the compound filling direction, too. Namely, it is preferable to determine the minimum width along the compound filling direction as the above-described minimum width (W), because the compound is easy to attach to the wall of the cavity, which faces the compound filling direction, to block the flow of the compound. For example, where the weighing and filling process is the process of horizontally moving a powder box storing the compound and having an open bottom, along an opening of the cavity, the above-described minimum width (W) may be the width measured along the moving direction (filling direction) of this powder box. For example, where the cavity has a bottomed cylindrical configuration, the difference in radius between an inner periphery and an outer periphery of the cavity corresponds

to the minimum width (W). The configuration of the cavity is determined according to the final configuration of the bonded magnet, and may be any configuration such as a plate-shaped, block-shaped, arc-shaped configuration, etc. in addition to the cylindrical configuration.

[0023] Where a succeeding orienting process, etc. is carried out in a different molding die from that used upon weighing and filling the compound, except for the case the succeeding orienting process, etc. is carried out in the same molding die as that used upon weighing and filling the compound, the weighed and filled compound must be transferred to the different molding die for the orienting process. At this time, the compound is required to be in a different state from that upon filling. Accordingly, for transferring the compound, it is convenient to compression-mold the weighed and filled compound in a cavity lightly to obtain a powder compact (green compact, pre-finished compact, blank compact), etc. similarly to the general power molding method. Namely, it is convenient that the weighing and filling process includes not only the process of weighing the compound and filling it into the cavity but also the powder molding process of compression-molding the compound filled in the cavity to obtain the powder compact to be subjected to the orienting process. It is preferable that this powder compact has such a molding degree that the compressed compound can be handled without collapsing. The molding pressure may be about 70 to 294 Mpa, for example.

[0024] This powder compact may be transferred from the weighing and filling process to the orienting process by hand or by jigs (cassettes, etc.) By

using the jigs, the shape retention of the powder compact becomes good, and automation, etc. can be facilitated. These transfer jigs may be also used in transferring the pre-formed body from the orienting process to the compactly bonding process in addition to the above-described case.

[0025] (2) Orienting process

The orienting process is the process of heating the compound, etc. subjected to the weighing and filling process to melt the thermosetting resin, and applying a magnetic field thereto. With this orienting process, each particle of the anisotropies magnet powder is oriented in a specific direction, thereby improving the magnetic properties of the bonded magnet. This orienting process is also carried out within the cavity of a predetermined molding die. This molding die is kept at a predetermined temperature depending on the kind of the thermosetting resin and the period of this process. That temperature is about 120 to 180 ℃, for example.

[0026] By applying heat, the thermosetting resin in the compound is softened or melted to lower the viscosity thereof. As a result, the anisotropic magnet powder becomes the state that it floats in a fluid of the molten thermosetting resin, thereby increasing the fluidity thereof. When the orientation magnetic field is applied in this state, the anisotropic magnet powder moves and turns to be oriented in a predetermined polar direction. In order to perform this orientation efficiently and certainly, it is preferable to apply the orientation magnetic field when the viscosity of the thermosetting resin becomes lowest.

[0027] In the orienting process of the present invention, the "softened state"

and the "molten state" are not strictly distinguished from each other, because it is sufficient that the thermosetting resin is heated so that the viscosity thereof lowers to enable the anisotropic magnet powder to turn and move therein. Of course, the degree of the orientation of the anisotropic magnet powder depends on the strength of the orientation magnetic field to be applied. The strength of this orientation magnetic field may be 320 to 800 kA/m, for example, provided that it is applied when the viscosity of the thermosetting resin lowers properly.

[0028] By applying heat to the thermosetting resin, it is first softened and melted to greatly lower the viscosity thereof, and reach a peak of the lowering of the viscosity. Then, when the viscosity passes the peak, the cross-linking reaction between molecules is promoted so that the viscosity is lowered and the thermosetting resin is hardened. As a result, the bonded magnet composed of oriented anisotropic magnet powder is obtained. While the thermosetting resin is heated at such a temperature that the hardening reaction proceeds, the hardening of the thermosetting resin gradually proceeds from the orienting process to the later-describing compactly bonding process. Where the preceding weighing and filling process is carried out at the temperature in the vicinity of the softening point, the hardening of the thermosetting resin may proceed in the weighing and filling process.

[0029] From these viewpoints, it is clear that in order to carry out these processes effectively, the hardening reaction of the thermosetting resin is needed to be controlled by properly adjusting the heating temperature and

heating time of the compound. The orienting process, for example, uses the step where the hardening reaction has not proceeded so much. And, the later-describing compactly bonding process uses the step where the thermosetting resin is hardened to the degree that it does not lose its fluidity but the oriented anisotropic magnet powder is kept compact after compression molding.

[0030] In the case the compactly bonding process is carried out in a different molding die except for the case the compactly bonding process is carried out in the same molding die as that used in the orienting process, the oriented anisotropic magnet powder, etc. is needed to be transferred to the different molding die for the compactly bonding process. Accordingly, it is preferable that the orienting process also include the pre-molding process of compression-molding the oriented anisotropic magnet powder and the thermosetting resin while heating, and making the hardening reaction proceed to such a degree as to preserve the oriented state of the magnet powder, thereby molding a pre-molded body to be subjected to the above-described compactly bonding process, similarly to the weighing and filling process. By molding the pre-molded body in the pre-molding process in this manner, the transfer from the orientating process to the compactly bonding process becomes facilitated.

[0031] The molding pressure in this pre-molding process may be about 147 to 343 Mpa, for example, and it is preferable that the molding pressure in this pre-molding process is higher than that in the above-described powder molding process (weighing and filling process) and lower than that in the

compactly bonding process. Upon proceeding from the orienting process of the anisotropic magnet powder to the pre-molding process, it is preferable to keep it for at least about 1 second after applying a magnetic field for orienting the anisotropic magnet powder sufficiently.

[0032] (3) Compactly bonding process

The compactly bonding process is the process of compression -molding the anisotropic magnet powder and the thermosetting resin which have been subjected to the orienting process, thereby preparing a bonded magnet compact in which the orientated anisotropic magnet powder is compactly bonded. In this process, bubbles existing in the anisotropic magnet powder and the thermosetting resin after the orienting process are discharged, and empty spaces therein are crushed, and consequently, bonded magnet compact with a high density, excellent magnetic properties and an excellent dimensional accuracy is obtained. This compactly bonding process is also carried out in a cavity of a predetermined molding die. This molding die is kept at a predetermined temperature depending on the kind of the thermosetting resin, period of process, etc. That temperature is about 120 to 180 ℃, for example. And the molding pressure ranges from about 686 to 882 Mpa, for example. It is preferable that this molding pressure is higher than the molding pressure in the pre-molding process (orienting process).

[0033] The bonded magnet compact obtained in this compactly bonding process may be a bonded magnet in which the thermosetting resin is completely hardened, or a bonded magnet in which the thermosetting resin is

incompletely hardened. Since it takes a long time to harden the thermosetting resin completely, it is more efficient to subject many bonded magnet compacts in which the thermosetting resin is incompletely hardened, to the heating and hardening treatment (cure heat treatment) in a batch processing.

[0034] (4) Lubricant applying process

In accordance with the present invention, it is preferable that a lubricant applying process of applying a lubricant at least on a surface of the powder compact obtained after the weighing and filling process is provided before the orienting process. With this process, first, sintering between anisotropic magnetic power (or compact thereof) and the molding die can be prevented in the orienting process (especially the pre-molding process) and the compactly bonding process. In addition, since the lubricant applying process is carried out prior to the orienting process, friction between particles of the compound (anisotropic magnetic powder) existing in the vicinity of the wall of the molding die is reduced, thereby promoting the orientation of the anisotropic magnetic powder. This results in a further highly oriented compact being obtained, thereby further improving the magnetic properties of the bonded magnet. Of course, according to the applying state and the applying time of the lubricant to the powder compact, the dimensions of the powder compact, etc. the lubricant does not stay in the vicinity of the surface of the powder compact, and the inside thereof can be impregnated with the lubricant. As the inside of the powder compact is impregnated with the lubricant, the anisotropic magnetic powder is further oriented highly.

[0035] The powder compact to which the lubricant is to be applied may have any configuration, but as the thickness of the powder compact is reduced, it is easily impregnated with the lubricant toward the inside thereof. In accordance with the present invention, such a thin powder compact of a stable quality can be readily obtained so as to be convenient.

[0036] The lubricant applying process is not limited to a specific method, but, for example, the lubricant applying process can be carried out by dipping the powder compact in the lubricant, spraying the lubricant on the powder compact, coating the powder compact with the lubricant, or the like method. Where the powder compact is dipped in the lubricant, the lubricant is readily applied to the powder compact sufficiently in a short time. Where the lubricant is sprayed on the powder compact or the powder compact is coated with the lubricant, the lubricant is readily applied to the surface of the powder compact uniformly.

[0037] It is preferable to use a liquid lubricant from the viewpoints of the applying properties to the powder compact, high orienting properties due to the impregnation into the powder compact, or the like. On the other hand, from the viewpoints of the prevention of the sintering of the powder compact (anisotropic magnetic powder) and the molding die, it is preferable to use a solid lubricant which can achieve high sintering preventing effect even in a high temperature range. Accordingly, it is preferable to use the lubricant in which the solid lubricant achieving high sintering preventing effect is homogeneously dispersed in liquid oil as a dispersing agent. Namely, it is preferable that the above-described lubricant is a mixture lubricant prepared

by mixing the solid lubricant in the liquid oil. It is preferable that the oil to be used in this method is composed of a chemical compound such as polyalkyl glycol, mineral oil, etc, which does not deteriorate the magnetic properties of the anisotropic magnetic powder and does not degenerate even when a high temperature (120 to 180 ℃, for example) is applied in the orienting process, etc. And the solid lubricant to be used with this method may be an inorganic substance or an organic substance.

[0038] And the lubricant may be a volatile lubricant which volatilizes during the orienting process without remaining in the compactly bonding process. In this case, the high orienting properties and the sintering preventing properties in the pre-molding process can be effected. And where the lubricant is a mixture lubricant composed of a volatile oil and the above-described solid lubricant, the solid lubricant remains even when the oil as the dispersing agent volatilizes, and accordingly, the sintering preventing effect can be obtained in the orienting process (pre-molding process) and the compactly bonding process.

[0039] The lubricant remaining after the compactly bonding process can be arbitrarily removed by leaving it alone, sucking it with an aspirator, or like method.

[0040] (5) Molding die

As described above, the method for manufacturing the bonded magnet in accordance with the present invention can be carried out in a single molding die. But, it is efficient to carry out each process in a different molding die,

considering the mass production properties, etc.

[0041] Namely, it is preferable that the weighing and filling process is carried out in a first molding die, the orienting process is carried out in a second molding die different from the first molding die, and the compactly bonding process is carried out in a third molding die different from the first and second molding dies.

[0042] And by using an exclusive molding die in every process, the molding die can be designed freely and the lifetime of the molding die can be prolonged. For example, since in the orienting process, the orientation magnetic field is applied, a magnetic material exhibiting a high magnetic permeability is desired to be used in at least one part of the second molding die, and actually, pure iron and permendur or the like are used. These materials for the molding die are relatively inferior in the friction resistance so as to be not suited to the material for the molding die, inherently. But, since the molding pressure in the orienting process is relatively small, as described above, the friction of the molding die, or the like does not involve any serious problem.

[0043] In the compactly bonding process, a relatively great molding pressure is applied so that the lifetime of the molding die becomes a serious problem, and actually, there are used the materials exhibiting excellent friction resistance, such as sintered hard alloy, tool steel, or the like. These materials do not exhibit a great magnetic permeability, but since in the compactly bonding process, the orientation magnetic field may not be applied

or if applied, a weak orientation magnetic field will do, it is sufficient to use these materials.

[0044] In addition, in the weighing and filling process, in order to improve the filling properties of the compound, it is preferable to use a non-magnetic material free from the influence of residual magnetization as the material for at least outer and inner walls defining the cavity.

[0045] By using a different molding die in every process in this manner, molding dies, each being suited to each process, can be readily provided. This results in the lifetime of the molding die being prolonged to reduce the apparatus cost. Of course, by separately providing the molding dies in the weighing and filling process and the orienting process, the method is readily applicable where there is a great difference in temperature between processes, as described above.

[0046] (6) Compound

The compound is mainly composed of the anisotropic magnet powder and the thermosetting resin, but can further contain additives such as a lubricant, hardening agent, hardening auxiliary agent, surface active agent , etc. The average particle diameter of the above-described compound is the diameter of the particles inclusive particles of these thermosetting resin, etc. The average particle diameter is an average of the weight based on the particle size distribution. Where the compound is filled in the cavity of which the above-described relative width ratio is small, it is preferable to use the compound of which the particle size distribution is made narrow, that is the

particle size is made similar to each other, by screening or like method.

[0047] The composition, kind or the like of the anisotropic magnet powder are not limited specifically, and any well-known magnet powder can be adopted. Any method for manufacturing these magnet powders will do. So-called rapid quenching solidification method, hydrogenation treatment method (d-HDDR method, HDDR method) will do.

[0048] In addition, the anisosropic magnet powder to be contained in the compound is not limited to a single kind of magnetic powder, and a plurality of kinds of magnet powder may be mixed and kneaded. As the anisotropic magnet powder becomes fine, the movement in the orientating process becomes possible to facilitate the orientation thereof. But, magnet powder obtained by arbitrarily granulating can be used.

[0049] Examples of the thermosetting resin include epoxy resin, phenol resin, melamine resin or the like. These thermosetting resins may attach to a periphery of the anisotropic magnet powder in a powder state, or the periphery of the anisotropic magnet powder may be coated with these thermosetting resins in a film state.

[0050] Examples of the additives include lubricants such as zinc stearate, aluminum stearate, alcohol-based lubricant, titanate-based or silane-based coupling agent, hardening agent such as 4 • 4'-diamino diphenyl methane (DDM), etc., hardening promoting agent such as TPP-S (trade name, manufactured by HOKKO CHEMICAL INDUSTRY CO., LTD.), etc., and a

small amount of these additives may be added to the compound. By virtue of these additives, the die releasing properties of the compact, the adjustment of the molding timing, the wetting properties and the adhesion of the magnet powder against the molten resin are improved.

[0051] The mixing ratio (volume ratios) of the anisotropic magnet powder and the thermosetting resin is about 80 to 90 volume % of anisotropic magnet power to about 10 to 20 volume % of thermosetting resin. The mass ratio of the anisotropic magnet powder and the thermosetting resin is about 95 to 99 mass % of anisotropic magnet powder to about 1 to 5 mass % of the thermosetting resin. About 0.1 to 0.5 volume % or about 0.2 to 0.5 mass % of the additives may be added. The above-described compound is obtained by mixing and kneading these anisotropic magnet powder, the thermosetting resin, etc. homogeneously with a mixer.

[0052] The preferable average particle diameter of the compound including the thermosetting resin is not greater than 212 μm. If the average particle diameter is too great, the moving and turning of the compound in the orienting process become difficult so that it is difficult to improve the magnetic properties. The lower limit of the average particle diameter depends on the composition of the anisotropic magnet powder, and accordingly cannot be generally specified. In the case of the NdFeB-based anisotropic magnetic powder, the preferable average diameter may be not less than 3 μm.

[0053] (7) Bonded magnet

The bonded magnet obtained by the method in accordance with the

present invention can have various configurations, dimensions, and magnetic properties, and can be used in various uses. As described above, the bonded magnet obtained by the method of the present invention may be a ring-shaped thin bonded magnet, an arc-shaped thin bonded magnet or a plate-shaped thin bonded magnet. Of course, the bonded magnet obtained by the method of the present invention is not limited to the thin bonded magnet. The direction of the orientation and magnetization may be vertical, horizontal, axial, radial, or the like. And any dimensions will do, but it is preferable to have the size enhancing the orienting properties. For example, in the case of the ring-shaped thin bonded magnet oriented in radial directions, the orientation in the axial direction scatters, if the bonded magnet is long in the axial direction relative to the radial directions. In this case, a plurality of ring-shaped thin bonded magnets, each being short in the axial direction, may be layered on each other to prolong in the axial direction. As described in Publication of unexamined JP patent application No. 11-186027, in order to obtain good magnetic properties, it is preferable to layer the molded bodies subjected to the orienting process on each other and form an integral magnet in the molding process. The bonded magnet compact obtained by the method of the present invention is polarized arbitrarily according to the use of the bonded magnet.

[0054] B. Examples

The present invention will be explained in more details with reference to the examples.

(Preparation of Compound)

The compound used in the present embodiment is obtained by mixing

NdFeB-based coarse powder and SmFeN-based fine powder as the anisotropic magnetic powder with a henschel mixer, adding an epoxy resin powder as the thermosetting resin to a mixed powder, and heating and kneading the mixed powder containing the epoxy resin powder with a banbury mixer at 110 ℃. The composition ratio of the NdFeB-based coarse powder, SmFeN-based fine powder and epoxy resin powder is 78 mass %, 20 mass % and 2 mass %. This compound has the arrangement that SmFeN-based fine powder exists around the NdFeB-based coarse powder, and this SmFeN-based fine powder and the epoxy resin surround the NdFeB-based coarse powder.

[0055] The above-described NdFeB-based coarse powder and SmFeN-based fine powder were prepared in the following manner.

(1) NdFeB-based coarse powder

An alloy ingot having the composition of 12. 5 at% of Nd, 6.4 at% of B, 0.3 at% of Ga, and 0.2 at% of Nb with the remainder being Fe was subjected to the d-HDDR treatment. More specifically, first, the alloy ingot (30 kg) having the above-described composition was melted and cast. The obtained ingot was subjected to the homogenizing treatment in an Ar gas atmosphere heated at 1140 to 1150 ℃ for 40 hours. This alloy ingot was further pulverized using a jaw crusher into coarsely crushed body having an average particle diameter of not more than 10 mm The coarsely crushed body was subjected to the d-HDDR treatment including a low-temperature hydrogenation process, a high-temperature hydrogenation process, a first evacuation process and a second evacuation process. Namely, a sufficient amount of hydrogen was made to be absorbed in each test alloy in a

hydrogen gas atmosphere of which the temperature is room temperature, and of which the hydrogen pressure is 100 kPa (low-temperature hydrogenation process). Next, each test alloy was subjected to the heat treatment for 480 minutes in a hydrogen gas atmosphere of which the temperature is 800 ℃ and of which the hydrogen pressure is 30 kPa (high-temperature hydrogenation process). Then, each test alloy was subjected to the heat treatment in a hydrogen gas atmosphere of which the hydrogen pressure ranges from 0.1 to 20 kPa for 160 minutes while keeping the temperature at 800 ℃ (first evacuation process). Finally, gases was drawn to the vacuum with a rotary pump and a diffusion pump for 60 minutes, and each test alloy was cooled in a vacuum atmosphere of 10^{-1} Pa or less (second evacuation process).

[0056] In this manner, about 10 kg of NDFeB-based anisotropic magnet powder per batch was obtained. The average particle diameter of the obtained anisotropic magnetic powder is classified with a sieve, and the weight of the powder of each class was measured, and the weighted average of the anisotrpic manetic powder obtained from the measured weight was about 106 μm.

[0057] In addition, the surface of the obtained NdFeB-based anisotropic magnetic powder was coated with a surface active agent. The coating of the surface active agent was carried out by adding a solution of the surface active agent to the NdFeB-based anisotropic magnetic powder, and vacuum-drying the solution while stirring it (coating process). The solution of the surface active agent was prepared by diluting a silane-based coupling

agent (manufactured by Nihon Unica CO., LTD. NUC silicone A-187) with ethanol to double the solution. In the present example, the NdFeB-based anisotropic magnetic powder coated with this surface active agent was called "NdFeB-based coarse powder".

[0058] (2) SmFeN-based fine powder

SmFeN-based anisotropic magnet powder on the market, which is composed of 10 at% of Sm and 13 at% of N with the remainder being Fe, (manufactured by SUMITOMO METAL MINING CO., LTD.) was coated with the surface active agent, similarly to the case of NdFeB-based coarse powder. In the present example, the SmFeN-based anisotropic magnet powder coated with the surface active agent was called "SmFeN-based fine powder". The average particle diameter of the SmFeN-based anisotropic magnet powder ranges from 2 to 3 μm.

[0059] (Manufacturing of bonded magnet)

A ring-shaped thin bonded magnet which finally has an outer diameter of ϕ30 and a height of 20 mm was manufactured using the above-described compound (average particle diameter d= 0.1 mm). Previously, a bonded magnet compact prior to polarization was manufactured in the later-describing processes. In the present example, by variously changing the inner diameter (thickness) thereof, a plurality of kinds of test pieces were manufactured. The inner diameter of each test piece was shown in Table 1.

[0060] (1) Weighing and filling process

The weighing and filling process was carried out using a first molding

device 30.

This first molding device 30 includes a cylindrical molding die 32 which has a molding hole 33 penetrating an axial center thereof, a column-shaped upper core 34 which extends upwardly of the axial center of this molding hole 33, a column-shaped lower core 35 which extends downwardly of the axial center of the molding hole 33 and is adapted to contact a lower end face of the upper core 34, a cylindrical upper punch 36 which is positioned on an upper side of a cylindrical cavity C1 provided between an outer peripheral surface of the upper core 34 or the lower core 35 and an inner surface of the molding hole 33, a cylindrical lower punch 37 which is positioned on a lower side of the cavity C1, a base part 38 of the upper punch 36, which is secured to an upper end of the upper punch 36, a base part 39 of a lower punch 37, which is secured to a lower end of the lower punch 37, a core driving device 20 for applying a pressure in the state that the upper core 34 and the lower core 35 are made to approach each other, and a punch driving device 21 for applying a pressure in the state that the base part 38 of the upper punch and the base part 39 of the lower punch are made to approach each other.

[0061] The weighing of the compound and the filling of the compound in the cavity C1 were carried out in the following manner.

The upper punch 36, the base part 38 of the upper punch, and the upper core 34 are raised upwardly. Next, the lower core 35 is held such that an upper end face thereof is located in flush with or slightly lower than the upper end face of the molding die 32. And, the lower punch 37 and the base part 39 of the lower punch are lowered so that the upper end face of the lower punch 37 is lower than the upper end face of the molding die 32. Thus,

the bottomed cylindrical cavity C1 for filling the compound is defined. This state is shown in FIG. 2. The inner diameter and the outer diameter of this cavity C1 are the same as those shown in Table 1. And, the filling amount of the compound depends on the volume of the cavity C1. Namely, the amount of the compound to be filled is weighed based on the volume of the cavity C1.

[0062] Next, as shown in FIG. 2, a powder box 11 containing the compound is placed on the upper surface of the molding die 32, etc. And the powder box 11 of which a bottom is open is moved horizontally. When the powder box 11 is moved to the upper side of the cavity C1, the compound falls from the open bottom thereof into the cavity C1 to fill the cavity C1. The powder box 11 reciprocates on the upper side of the cavity C1 until the cavity C1 is filled with the compound. And, at last, the compound is leveled, whereby a predetermined amount of compound is filled in the cavity C1. Thus, the weighing and filling of the compound are completed.

[0063] In the present example, no heater is provided in the molding die 32, etc. So, the temperature of the molding die is room temperature (30℃). At least the molding die 32, lower core 35 and lower punch 37 for contacting the compound upon the filling thereof are about room temperature. Therefore, at this time, the epoxy resin in the compound does not soften so as not to attach to walls 32a and 35a of the cavity C1. Accordingly, the compound is filled in the narrow cavity C1 smoothly. More specifically, the compound is filled in all of parts A, B, A', etc. of the cavity C1 homogeneously.

[0064] The first molding die of the present invention is composed of at least

the molding die 32, lower core 35 and lower punch 37. Of course, the first molding die may have the upper core 34 and upper punch 36.

[0065] If the molding die 32, lower core 35 and lower punch 37 are at high temperatures (not lower than the softening point of the epoxy resin) upon filling the compound, the epoxy resin in the compound softens and melts to attach to the walls 32a and 35a of the cavity C1. As a result, an upper inlet opening of the cavity C1 becomes locally closed to obstruct the smooth filling of the compound. These phenomena are easy to occur in the part A or part A', which are shown in FIG. 2(a). This is because the width W in the moving direction of the powder box 11 is narrow. On the other hand, even if the compound attaches to the walls 32a and 35a in the part B, etc. the compound is easy to fill in the part B, etc. as compared with the part A, etc., because the inlet opening of the compound substantially enlarges in the moving direction of the powder box 11. Where the molding die 32, etc. is at high temperatures, the filling state of the compound depends on the positions in the cavity C1, even if the cavity C1 has a ring-shaped configuration. Consequently, the parts A and A' are filled with the compound roughly, whereas the part B is filled with the compound closely, whereby the density of the filled compound becomes non-uniform. Where the width of the cavity C1 is narrow, such non-uniform density cannot be corrected even by applying vibrations thereto so that, like the case of the present embodiment, it is very effective to keep the temperature of the molding die to a low temperature (lower than the softening point of the epoxy resin).

[0066] Next, the compound thus filled in the cavity C1 was

compression-molded. Upon compression-molding, first, the upper core 34 and the lower core 35 are made to contact each other with a core driving device 20, as shown in FIG. 1. And, the upper punch 36 and the lower punch 37 are made to approach each other with a punch driving device 21, thereby pressing the compound in the cavity C1 upwardly and downwardly. Thus, a pre-finished compact (powder compact) was obtained (powder molding process). In this process, the molding pressure was determined to 70 Mpa. And it took five seconds in total to fill the compound into the cavity C1 and obtain the pre-finished compact.

[0067] (2) (Lubricant applying process)

The pre-finished compact obtained in the weighing and filling process was taken from the cavity C1 of the first molding device 30. And this pre-finished compact was immersed in a mixture lubricant for 2 seconds. The mixture lubricant was prepared by mixing a solid lubricant and polyalkyl glycol in the mass ratio of 2 to 98. The test piece No. 8 shown in Table 1 was subjected to the orienting process after the weighing and filling process without subjected to this lubricant applying process. The available ratio of the solid lubricant is about from 1 to 30.

[0068] (3) Orienting process

The orienting process was carried out using a second molding device 50 shown in FIG. 3.

This second molding device 50 includes a cylindrical molding die 52 which is provided with a heating source 51 and has a molding hole 53 penetrating an axial center thereof, a column-shaped upper core 54 which

extends upwardly of the axial center of this molding hole 53, a column-shaped lower core 55 which extends downwardly of the axial center of the molding hole 53 and is adapted to contact a lower end face of the upper core 54, a cylindrical upper punch 56 which is positioned on an upper side of a cylindrical cavity C2 provided between an outer peripheral surface of the upper core 54 or the lower core 55 and an inner surface of the molding hole 53, a cylindrical lower punch 57 which is positioned on a lower side of the cavity C2, a base part 58 of the upper punch, which is secured to an upper end of the upper punch 56, a base part 59 of a lower punch, which is secured to a lower end of the lower punch 57, a core driving device 60 for making the upper core 54 and the lower core 55 approach each other, and applying a pressure thereto, a punch driving device 61 for making the base part 38 of the upper punch and the base part 39 of the lower punch approach each other, and applying a pressure thereto, and an orientation magnetic field device 40.

[0069] The orientation magnetic field device 40 is composed of electromagnetic coils 41 and 42 provided so as to face each other in the axial direction with respect to the molding die 52. And the molding die 52, upper punch 56 and lower punch 57 are composed of a nonmagnetic material, and the upper core 54, lower core 55, base part 58 of the upper punch and base part 59 of the lower punch are composed of a magnetic material. And lines of magnetic force, which are emitted from the electromagnetic coils 41 and 42 of the orientation magnetic field device 40 pass the magnetic materials thereof, turn in radial directions toward the outer periphery of the cavity C2 from the vicinity of the center of the cavity C2, and return to the

electromagnetic coils 41 and 42. With the formation of this magnetic circuit, a magnetic field directing in radial directions is provided in the cavity C2, thereby orienting each magnet powder in radial directions (See FIG. 5).

[0070] The pre-finished compact in which the above-described mixture lubricant is made to be impregnated was placed in the cavity C2 of the second molding device 50, and subjected to the heating, orienting and compression-molding processes, thereby obtaining a pre-molded body. First, the heating process was carried out by keeping the temperature of the molding die at 140 ℃ and for 5 seconds. This results in the epoxy resin in the compound becoming softened and melted. Then, the orientation magnetic field was applied to the compound with the orientation magnetic field device 40 for 3 seconds before and after the viscosity of the epoxy resin became lowest. And the compound was compression-molded under 196 Mpa to obtain a pre-molded body (pre-molding process). During these processes, the temperature of the molding die was kept at 140 ℃ constantly. And it took 10 seconds in total to transfer the pre-finished compact to the cavity C2 and obtain the pre-molded body. The second molding die of the present invention includes a molding die 52, upper core 54, lower core 55, upper punch 56 and lower punch 57.

[0071] (4) Compactly bonding process

The compactly bonding process was carried out using a third molding device 70 shown in FIG. 4.

This third molding device 70 includes a cylindrical molding die 72 which has a molding hole 73 penetrating an axial center thereof, a

column-shaped upper core 74 which extends upwardly of the axial center of this molding hole 73, a column-shaped lower core 75 which extends downwardly of the axial center of the molding hole 73 and is adapted to contact a lower end face of the upper core 74, a cylindrical upper punch 76 which is positioned on an upper side of a cylindrical cavity C3 provided between an outer peripheral surface of the upper core 74 or the lower core 75 and an inner surface of the molding hole 73, a cylindrical lower punch 77 which is positioned on a lower side of the cavity C3, a base part 78 of the upper punch, which is secured to an upper end of the upper punch 76, a base part 79 of a lower punch, which is secured to a lower end of the lower punch 77, a core driving device 80 for making the upper core 74 and the lower core 75 approach each other, and applying a pressure thereto, and a punch driving device 81 for bringing the base part 78 of the upper punch and the base part 79 of the lower punch close to each other, and applying a pressure thereto.

[0072] The pre-molded body was placed in the cavity C3 of the third molding device 70, and subjected to the heating and compression-molding process, thereby obtaining a bonded magnet compact. This heating and compression-molding process was carried out by keeping the temperature and the molding pressure of the molding die at 140 ℃ and under 784 Mpa for 5 seconds. This results in the pre-molded body becoming more compact, and the epoxy resin becoming hardened, and accordingly, a bonded magnet compact with high dimensional accuracy was obtained. And it took 8 seconds in total to transfer the pre-molded body to the cavity C3 and obtain the bonded magnet compact.

[0073] In the present example, the third molding die of the present invention is composed of a molding die 72, upper core 74, lower core 75, upper punch 76 and lower punch 77. And in the present example, the transfer from the weighing and filling process to the orienting process, and the transfer from the orienting process to the compactly bonding process were carried out automatically while holding each compact with cassettes.

[0074] (5) Others

To sufficiently harden the epoxy resin, the bonded magnet compact was placed in a furnace of 150 ℃ for 30 minutes and subjected to the thermal hardening treatment.

[0075] Furthermore, the bonded magnet compact after the thermal hardening treatment was polarized to eight magnetic poles at regular intervals with the inner side thereof as S pole and the outer side thereof as N pole. The polarization was carried out in the condition of pulse-magnetization with a magnetomotive force of 35 kAT. Thus, as shown in FIG. 5, a radially oriented ring-shaped bonded magnet having eight magnetic poles was obtained.

[0076] (Measurement of test pieces)

The magnetic properties of each of the ring-shaped bonded magnets thus obtained were measured. The measurement results were shown together in Table 1. The magnetic properties were obtained by continuously measuring the surface magnetic flux of each bonded magnet in a circumferential direction thereof. Table 1 shows the maximum value of the

surface magnetic flux and the variation of the surface magnetic flux, which is the difference between the maximum value of the surface magnetic flux and the minimum value thereof.

[0077] (Comparative examples)

As comparative examples, ring-shaped bonded magnets, each having a similar arrangement to those of the examples of the present invention, were manufactured by the two-stepped molding method disclosed in the above described patent document 2 (Publication of unexamined JP patent application No. Hei 10-22153), and the measurement results of the magnetic properties of the comparative examples were shown together in Table 1. These comparative examples were obtained by filling a compound in a cavity of a molding die of 140 ℃, and pre-molding at the same temperature.

[0078] (Other example)

As other example, a bonded magnet having a similar arrangement to the test piece No. 4 was manufactured using the molding die of which the temperature is 60 ℃ in the weighing and filling process. The magnetic properties of the manufactured bonded magnet were shown in Table 2. In Table 2, the measurement results of the test pieces No. 4 and No. C4 were shown together for comparison.

[0079] (Evaluation)

(1) The comparison between the test pieces No. 3 through 7 and the test pieces No. C3 through C7 in Table 1 showed that there was no great difference in the maximum values of the surface magnetic flux, but there was

a great difference in the variations of the surface magnetic flux. More specifically, in the examples of the present invention, the scattering in the surface magnetic flux was very small over the entire circumference thereof so that the magnetic properties thereof were uniform. In contrast, in the comparative examples, the scattering in the surface magnetic flux was very large. In particular, as the thickness (W) of the ring-shaped bonded magnet decreases, such tendency was increased, and in the case of the test piece No. C3, for example, the scattering in the surface magnetic flux was about ten times as large as that of the test piece No. 3. This also means that, in the cases of the examples of the present invention, the scattering in the magnetic properties can be restrained to about one tenth of that of the conventional cases.

[0080] As is apparent from the measurement results of the test pieces No. C1 and No.C2, in the cases of the thin bonded magnets of which the relative width ratio is not more than 4, bonded magnets could not molded with the conventional method. In contrast, where the method of the present invention is adopted, as shown in the test pieces No. 1 and No. 2 of the examples of the present invention, the thin bonded magnet could be molded without generating any crack. No problem did not occur upon molding the thin bonded magnet. And in the cases of the test pieces No. 1 and No. 2, the scattering in the magnetic properties was very small.

As is apparent from the measurement results of the test piece No. C7, where the relative width ratio enlarges to about 20, the filling passages for the compound are ensured, and the variation of the surface magnetic flux also decreases.

And, as is apparent from the comparison between the test piece No. 7 and the test piece No. 8, by carrying out the lubricant applying process, the variation of the surface magnetic flux did not change, but the surface magnetic flux was improved. The present inventors' studies show that by carrying out the lubricant applying process, the surface magnetic flux was improved by 5 to 10 %.

[0081] (2) As is apparent from the measurement results of the test piece No. 8 shown in Table 2, even when the temperature of the molding die in the weighing and filling process is 60 ℃, the bonded magnet can be molded, similarly to the case the temperature of the molding die is 30 ℃. In addition, it could be confirmed that the magnetic properties of the bonded magnet of the test piece No. 8 did not greatly differ from those of the bonded magnet obtained at the molding die temperature of 30 ℃. From this result, it can be considered that the method of the present invention achieves its effect sufficiently as far as the temperature of the molding die is lower than the softening point (97 ℃ (after heating and kneading)) of the thermosetting resin (epoxy resin).

Table 1

Test Pieces No.		Inner Diameter of Bonded Magnet (Inner Diameter of Cavity) (mm)	Thickness of Bonded Magnet (W) (mm)	Relative Width Ratio (W/d) (mm)	Maximum Value of Surface Magnetic Flux (mT)	Variation of Surface Magnetic Flux (Maximum Value−Minimum Value) (mT)	Remarks
Examples	1	Φ29.6	0.2	2	70	1.5	Three-stepped Molding Temperature of Molding Die in Weighing and Filling: 30°C Test Piece No. 8: Without Lubricant Applying Process
	2	Φ29.2	0.4	4	120	2.0	
	3	Φ28.6	0.7	7	180	3.0	
	4	Φ28.0	1.0	10	230	2.5	
	5	Φ27.6	1.2	12	250	2.5	
	6	Φ27.0	1.5	15	280	2.5	
	7	Φ26.0	2.0	20	320	3.0	
	8	Φ26.0	2.0	20	300	3.0	
Comparative Examples	C1	Φ29.6	0.2	2	Not Moldable	—	Two-stepped Molding Temperature of Molding Die in Weighing and Filling: 140°C
	C2	Φ29.2	0.4	4	↑	—	
	C3	Φ28.6	0.7	7	150	30.0	
	C4	Φ28.0	1.0	10	220	23.0	
	C5	Φ27.6	1.2	12	250	18.0	
	C6	Φ27.0	1.5	15	280	15.0	
	C7	Φ26.0	2.0	20	320	12.0	

Outer Diameter of Bonded Magnet: ϕ30mm x Height: 20mm
Average Particle Diameter d of Compound: 0. 1mm

Table 2

Test Pieces No.		Temperature of Molding Die in Weighing and Filling (℃)	Maximum Value of Surface Magnetic Flux (mT)	Variation of Surface Magnetic Flux (Maximum Value-Minimum Value) (mT)	Remarks
Examples	4	30	230	2.5	Three-stepped Molding
	8	60	225	3.5	
Comparative Examples	C4	120	220	23.0	Two-stepped Molding

Bonded Magnet: Outer Diameter ϕ 30mm x Inner Diameter ϕ 28mm x Height: 20mm(ThicknessW: 1mm)
Average Particle Diameter d of Compound: 0. 1mm
Relative Width Ratio(W/d): 10